# CHARACTERIZATION OF CARVED RHYOLITE TUFF–THE HIEROGLYPHIC STAIRWAY OF COPÁN, HONDURAS

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## ABSTRACT

*The Hieroglyphic Stairway at Copán in Northwest Honduras is the longest inscription known from the Ancient Maya. As part of a larger conservation project of the Instituto Hondureño de Antropología e Historia (IHAH) and the Getty Conservation Institute (GCI), blocks of uncarved green and buff volcanic tuff as well as samples of flaking tuff from the Hieroglyphic Stairway, were characterized for their material properties and state of decay. Flaking appears to be connected to selective dissolution, hygric cycling, lichen hyphae and calcite precipitation in stone fractures. These results represent the first comprehensive characterization of these materials and aid the understanding of material durability, behavior and conservation for this important site.*

**KEY WORDS**
*Copán, Honduras, Tuff, Physico-Mechanical Testing, Flaking*

## INTRODUCTION

The Hieroglyphic Stairway at the ancient Mayan site of Copán, Honduras, was built during the 8th century C.E. Carved on its risers is the longest known inscription from ancient Mesoamerica, a unique historical account of four centuries of the Copán dynasty (Maudslay 1889). Over the years, the deterioration of the volcanic tuff, mainly through millimeter-scale flaking, has been a major cause of concern because it directly impacts the readability of the carved text (Hale, 1979). A joint project of the Instituto Hondureño de Antropología e Historia and the Getty Conservation Institute was initiated to establish a long-term conservation strategy for the Stairway. A tarp first installed in 1985 currently shelters the stairway (Fig. 1).

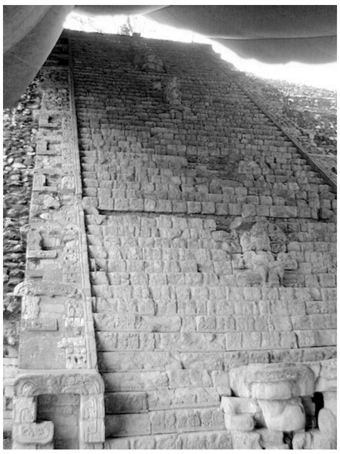


Figure 1: The Hieroglyphic Stairway, with shelter, April 2000

## MATERIALS AND METHODS

Standard methods were used to characterize the stone samples. XRD, XRF, and IC methods were used to identify mineralogical and chemical composition. For microanalysis and textural characterization, optical and electron microscopy (PLM, ESEM/EDS and EMPA) were used. Physical-mechanical properties measured for the Copán stone included measurements of compressive strength [BS EN 1926 (1999)], hygric dilatation [RILEM II.7], and drying kinetics [RILEM I.4. and RILEM II.5]. The capillary water absorption coefficient (W) was determined using a modified procedure based on DIN 52617. Water vapor diffusion was performed in accordance with DIN EN ISO 12572 (1997).

## RESULTS

### STONE CHARACTERIZATION

The bedrock of the Copán valley consists mainly of Tertiary age volcanic deposits of rhyolitic and andesitic ashflow tuffs, biotite tuffs, and some basalt known regionally as the Padre Miguel Group. Based on chemical and mineralogical analyses, the main stone at Copán is a green andesite to rhyolite volcaniclastic tuff. Tuff is a rock composed of volcanic ash which has been compacted. Ash is unconsolidated sediment, while tuff is the consolidated equivalent. This tuff originally contained ash (volcanic glass) and larger mineral fragments such as feldspar, quartz and mica. The bulk silica content of the rock is about 70 percent $SiO_2$ by weight.

The stone used in The Hieroglyphic Stairway is a 14 million-year-old welded rhyolite tuff containing inclusions of quartz, feldpsar and weathered chlorite. The original glass matrix of the stone has been largely altered to fine-grained zeolites, quartz and authigenic feldspar.

Copán stone has undergone substantial alteration since burial, with zeolites, quartz, and sanidine largely replacing the original glass matrix, and mineral fragments being dissolved or altered to a lesser degree. Two alteration textures were created during the transformation from a volcanic ash to a tuff. In the first texture the original glass matrix has been replaced by small crystals (4-10 μm) of mordenite (a zeolite), microcrystalline quartz, and some sanidine feldspar, leaving behind substantial original porosity (~20%). A second texture is also observed wherein the glass has been replaced by extremely fine crystals (<1-2 μm) of mordenite or heulandite (zeolites), subsequently followed by fine sanidine (1-4 μm) and some microcrystalline quartz. The first texture leaves the stone more crystalline, while the second has a chalky surface texture and a very low moisture transport rate. These textures are most likely related to the timing and intensity of burial alteration of the original, unstable volcanic ash. There is significant variation in the type, amount and homogeneity of distribution of large crystals (feldspar, quartz, mica, etc.) in the various stone types at Copán. However, the matrix, which makes up the bulk of the stone, has a more consistent composition (microcrystalline mordenite, quartz and sanidine having replaced shards of volcanic glass during devitrification).

Copán stone has some potential for inherent vice in the area of mineral transformations associated with liquid water and expansive behavior. Specifically, in some parts of the stone feldspars are partially dissolved, and biotite (mica) is altered to chlorite + iron hydroxides, and clay. The products of these reactions may respond to humidity fluctuations. Plagioclase feldspar crystals (often partially dissolved) are more common in the red stone than in the green stone at Copán; however, these crystals do not appear to be associated with significant residual clay formation.

In general, Copán stone has a pore geometry that is susceptible to salt damage, as characterized by substantial microporosity and low liquid water transport rate.

Ion Chromatography (IC) results on Copán stone flakes from the stairway generally low concentrations of salts with the exception of a small area at the top of the stairway adjacent to some recent cement additions. One sample shows high concentrations of soluble chloride and sulfate ions and very high concentrations of calcium and nitrate (3-6%). The other sample shows high concentrations of soluble calcium and nitrate ions (1.5-3.75%). Nitrate is often associated with organic material and bird droppings, and is present at lower levels on rest of the stairway, as would be expected in an area with abundant organic material and a high rate of decay of organic material. Most of the stairway has relatively low salt concentrations.

## ANALYSIS OF STONE FLAKES FROM THE STAIRWAY

Often, below detached flakes, whitish efflorescences are observed at the stairway. The cross section of the flake shows surface parallel cracks, which are filled partly with white crystals. In UV light, the filling material is more fluorescent, suggesting incorporation of organic material, which is frequently found in patinas. The analysis in ESEM-EDS reveals a precipitation of calcite along those cracks (Fig. 2), which was confirmed by XRD analysis. Furthermore the bottom of the flakes, in the more crumbly horizon of detachment, is depleted in Silicon and Oxygen, suggesting a selective dissolution of these components in the course of weathering. This general pattern is visible in several stone flakes.

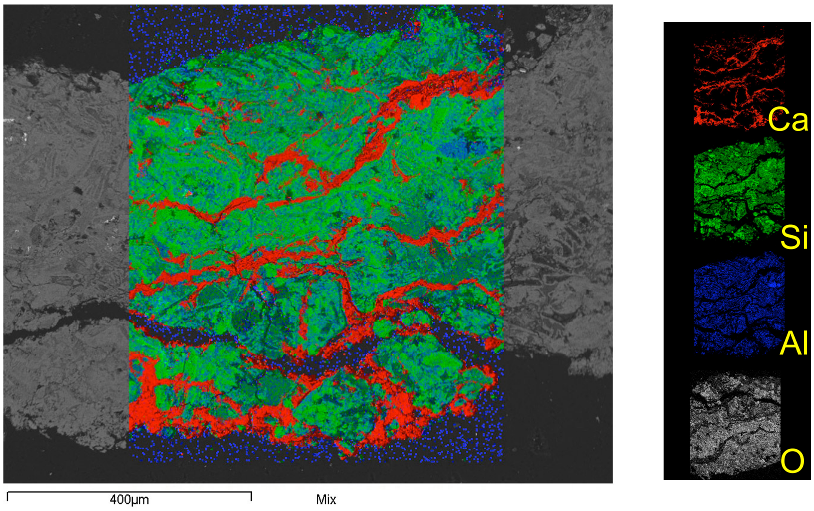
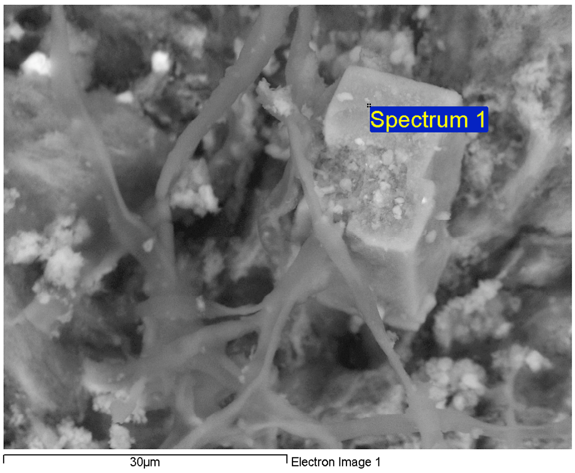



Figure 2. ESEM/EDS image of Copán stone flake in BSE mode with X-ray overlayer showing distribution of calcite in fractures (false color-red). Scale is 400 microns.

Often the cracks in the flakes are also filled with organic material, including remnant fungal hyphae, which sometimes can be associated with calcite formation (Fig. 3; Chen 2000). However, the origin of the surface parallel cracks cannot be clarified completely. They could also be the result of subsequent wetting-drying cycles, associated with hygric dilatation of the immediate surface, dissolution of more soluble stone components and sheer stress. In fact, the thickness of the flakes corresponds quite well to the depth position of the maximum moisture content for Copan stone in average over time (see later discussion).

## BULK STONE PHYSICAL PROPERTIES

One of the concerns at Copán is to understand the different types of stone present at the site and their composition, texture, properties and hygric behavior. The stones were subject to a range of tests which are reported here.



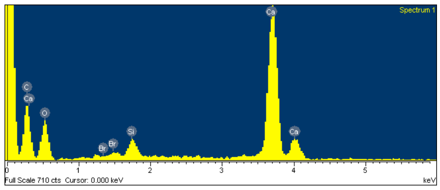




Figure 3. Copán stone flake with calcite and fungi on flake surface, ESEM/EDS.

### A) Strength

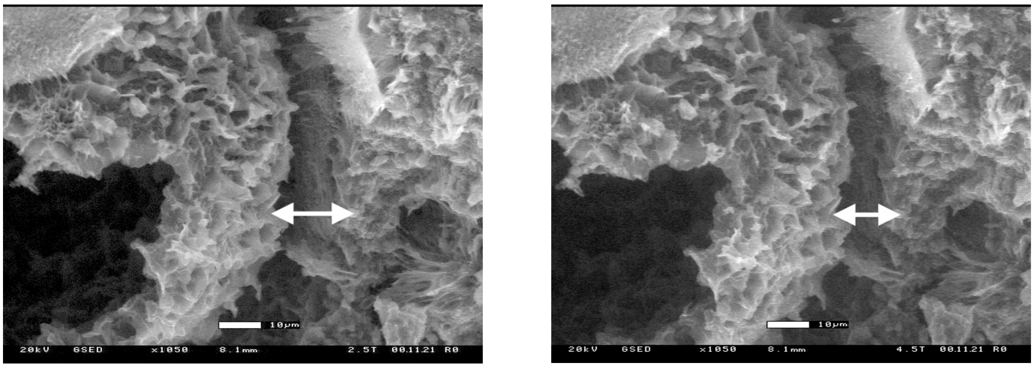
A fundamental parameter of building materials is compressive strength. Also, other parameters, such as tensile strength and overall durability, often correlate with compressive strength. The results indicate generally strong materials, however the buff stone has about half the strength of the fine green stone (55 MPa vs. 100 MPa), while the coarse green stone has a strength less than the fine green (80 MPa), but significantly higher than the buff stone (55MPa). The results from the Copán stone suggest significant differences between the different types of stone, which may be related to different behavior in resisting decay. In the next sections, further differences between the stone types are documented.

### B) Hygric Dilatation

Often when a stone is put into water it swells slightly. If significant amounts of swellable clays are present then the expansion can be a cause of physical stress and an important factor in the decay process. The bulk hygric dilatation was measured for three Copán stones (buff, fine green and coarse green). Analysis of the fine fraction showed a small amount of swellable clays present (2-6%). The results show that the dilatation (expansion) of Copán stone is within the range expected for this stone type, however there is substantial variation depending on the sample orientation and lithology (250-590 µm/m). If the clay is not distributed evenly throughout the stone, but is concentrated in specific zones; then clay swelling may be important source of stress especially on a microscale (Fig. 4). Shear stress may also develop as the stone surface wets and dries at a different rate than the bulk stone.

### C) Capillarity

Analysis of the rate of water uptake from each stone shows that fine green stone (BF1) has a much slower water uptake than the buff stone. The coarser green stones fall in between the fine green and buff stones. Water uptake is an important parameter, because it controls the location of the water/air interface, which affects salt accumulation, and stress from wetting and drying.




a b

Figure 4 a,b. Expansion and contraction of clay in ESEM during wetting-drying cycles, sample BF1.

The W-values are relatively low, ranging for the green stone between 0.5 and 2.3. The buff stone shows higher values of 3.8 kg/m$^2\sqrt{}$h. Even more significant is the difference regarding the B-values, which describe the water penetration behavior. For the buff lithotype, the penetration reaches with 0.8 cm/$\sqrt{}$h almost the double depth of the green stone. This means, during a rain event of approx. 1 hour, the moisture front in the green stone does not exceed 3-4 mm. Comparing W- and B- values for both lithotypes, the green Copán stone seems to be more susceptible to flaking, while intergranular disintegration can contribute more to the weathering of the buff variety.

D) Drying Kinetics (Drying Index)

The rate of drying of the stone is controlled by its pore structure. There is typically a change in slope of the drying curve (decrease in drying rate) that reflects the shift from a continuous, liquid film transporting fluid to the surface, and a discontinuous film dominated by water vapor transport. A strong difference in the drying rate is noted, with the buff Copán stone drying more quickly than the fine green stone. This is consistent with some observations of scaling on the green stone and uniform recession of the buff material. Both stones tend to keep moisture inside for a long time, showing also how different the times spans between water uptake and release can be due to the fact that the uptake can take place by capillarity, while the drying is restricted to the diffusion mechanism of evaporation. For the green stone, the horizon of evaporation withdraws beneath the surface approximately 10-15 hours after the last capillary wetting.

E) Water Vapor Diffusion Resistance

The resistance to water vapor transport was measured to determine the rate at which water can travel through the stone in the gas phase, as opposed to liquid water. The results indicate that relative transport rates are low, suggesting slow overall drying. Differences in diffusion resistance between the Copán stone types were less than the variation measured between sample replicates. The values for the different varieties show similar results, with a slightly higher vapor resistance in the coarse green samples.

## FINAL REMARKS

Based on the measured physico-mechanical properties of the stone, the moisture and temperature profiles were calculated using the program WUFI which was developed for the calculation of simultaneous heat and moisture transport (Fig. 5; Künzel 1995; Fraunhofer Institute for Building Physics). Without the current tarp over the stairway (Fig. 1), the stone surface would likely contain up to 40 kg/m$^3$ water (Fig. 5, left), while under the shelter, a continuous drying process takes place (Fig. 5, right). These results represent the first comprehensive characterization of Copán stone and contribute to the selection of appropriate repair materials and the development of a comprehensive conservation plan for this important monument.

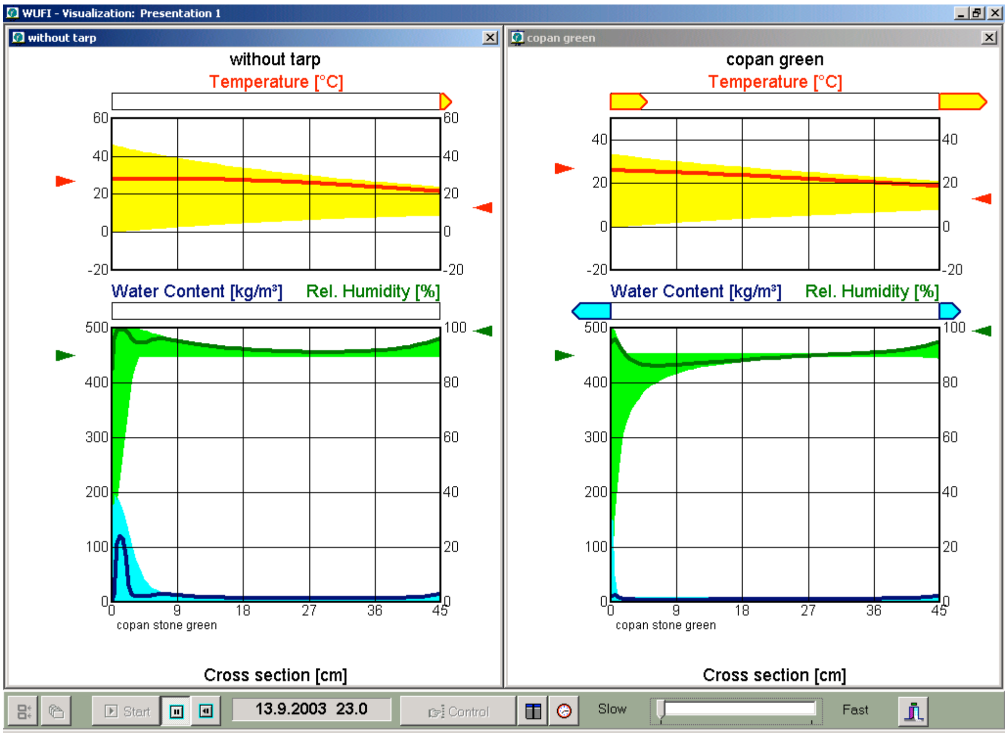



Figure 5. WUFI-Calculation for depth profiles of water content, relative humidity and temperature for the Copán staircase (green stone) with (right) and without (left) the tarp.

## ACKNOWLEDGMENTS

The authors would like to thank Barbara and William Fash and the Peabody Museum of American Archaeology and Ethnology for their generous assistance. We also acknowledge the partnership of the Instituto Hondureño de Antropología e Historia (IHAH), in particular Copán staff members Oscar Cruz and Ruffino Membraño. We also appreciate the advice and encouragement of Ricardo Agurcia and the Asociación Copán. Many GCI and Getty Museum staff have contributed to the project at different times. The project has also benefited greatly from the involvement of architectural conservator William Martin of English Heritage, and from the conservation professionals who attended the September 2000 Copán Experts Meeting.

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